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Mechanical Hazard Simulator of PLC-Based Automation Technology According to ISO 12100

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Abstract

Automation technology is expected can enhance productivity, reduce unnecessary cost, and avoid the potential upcoming accidents. However, many automation machineries don't fulfil safety requirements and have no third party safety certification. This situation requires internal risk assessment as a gate before technology deployment in order to reduce potential hazardous events. This research applies internal risk assessment of Programmable Logic Controller (PLC)-based automation technology according to ISO 12100. Mechanical hazard simulator is built to describe the potential hazard and estimate risk level. Alternative solutions for technology retrofit is selected and built to reduce risk level. At the end of the research, risk level comparison is presented as the evidence of risk level reduction.

Keywords: *Risk assessment, Risk level, Programmable Logic Controller, Retrofit, ISO 12100*

Abstrak

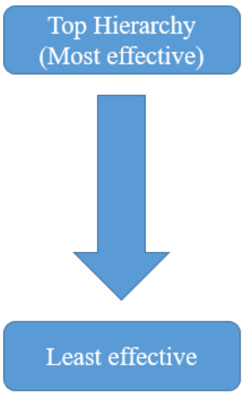
Teknologi otomasi diharapkan mampu meningkatkan produktivitas, mengurangi biaya yang tidak diperlukan, dan mencegah potensi kecelakaan kerja di massa depan. Namun, banyak mesin otomasi tidak memenuhi persyaratan keselamatan kerja dan tidak memiliki sertifikasi dari pihak ketiga. Situasi ini mensyaratkan analisis resiko secara mandiri oleh pengguna mesin untuk mengurangi resiko kecelakaan kerja. Penelitian ini menerapkan analsisi resiko kecelakaan kerja secara mandiri untuk teknologi otomasi berbasis PLC berdasarkan ISO 12100. Simulator bahaya mekanik dibuat untuk menggambarkan potensi kecelakaan kerja dan mengestimasi level bahaya. Alternatif solusi untuk modifikasi teknologi dipilih dan dikembangkan untuk mengurangi level bahaya. Pada akhir penelitian, perbandingan tingkat bahaya, sebelum dan sesudah modifikasi teknologi, disajikan sebagai bukti adanya penurunan level bahaya.

Kata-kata kunci: Penilaian Bahaya, Tingkat Bahaya, *Programmable Logic Controller*, Modifikasi, ISO 12100

1. Introduction

Automation is one of the most important instruments in industrial revolution 4.0 [1]. It has a lot of purposes, one of them is to increase the level of safety [2]. In order to run automation machinery safely, there must be alignments for three main elements; people, technology, and process [3]. Aligning these instruments aims to let people operate automation machine safely for specific purpose to enhance productivity and reduce unnecessary cost, especially for medical treatment or any indirect cost when an accident occurred during operation [4]. Accident rate in Indonesia goes up from 370,747 cases in 2023 to 462,241 cases in 2024 [5]. Around 88% of accidents occurred due to unsafe activities, and 12% because of unsafe condition [6]. Unsafe activities frequencies can be reduced by giving training, proper warning sign, and providing adequate personal protective equipment (PPE) [7-9], while unsafe condition can be evaluated by observing the environmental situation.

To avoid future potential accidents, upcoming automation technology must be certified before it is deployed to industry or academia. However, many automation machines don't fulfil safety requirements. They don't have any third party certification due to expensive costs, which means the machines still possess unknown potential hazards and not allowed to be operated. Therefore, internal risk assessment need to be performed as the first gate for automation technology deployment [10-13]. There are five established hierarchies for risk assessment, it can't jump on into the lower level without ensuring the possibility of implementing higher one first., as shown in Figure 1 [14].



No	Hierarchy	Detail
1	Elimination or Substitution	Hazard elimination Material substitution
2	Engineering Control	Adding Device
3	Warning Sign	Put warning sigh
4	Training	Safety training
5	Personal Protective Equipment	Mask, gloves, safety shoes

Figure 1. Safety hierarchy

Elimination or substitution hierarchy mostly can't be performed because it is the main product function of automation technology, for instance auto cutting machine. Cutter can't be eliminated or separated from the automatic cutting machine components, even people may get injured because of it. Engineering control, as second hierarchy need to be evaluated before moving to the lower ones. To evaluate risk level of automation technology, ISO 12100 provides the standardized hazard types, risk level calculation, and steps that can be followed sequentially [15].

This research applies internal risk assessment of automation technology with Programmable Logic Controller (PLC) controller based on ISO 12100. PLC-based automation is chosen because it is one of the most common control system used in industrial automation [16-18]. Prototypes of PLC-based automation technology is built to simulate the potential upcoming accidents, estimate risk level, and predict the necessary additional devices to be installed in order to reduce risk level. Retrofit technology might be necessary to reduce the risk level. At the end of this research, new risk level of retrofit simulator is presented as the evidence of risk level reduction.

2. Method

This research comprises three main activities, design and fabrication of hazard simulator, retrofit simulator, and risk level estimation, as presented in Figure 2.

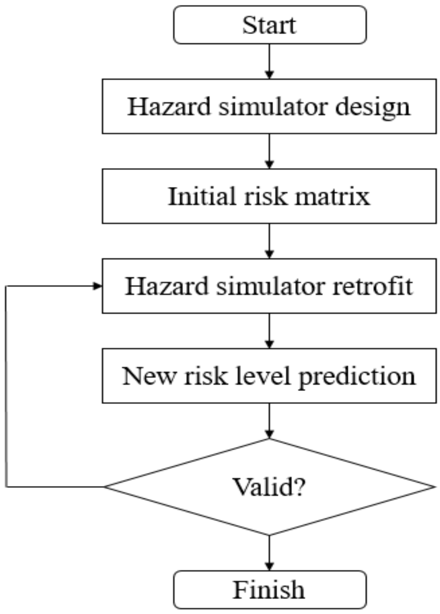


Figure 2. Research flowchart

2.1 Hazard simulator

Hazard simulator is expected can represent the mechanism of automation machine that refer to existing common process, and its hazardous event which follows ISO 12100. Based on previous well established automation machinery, such as auto printing machine, auto cutting machine, auto packaging machine, auto removing machine, all those machines have three common sequences; loading, main process, and offloading [19-23], as illustrated in Figure 3.

Figure 3. Research Flowchart

Actuators are necessary to be determined in order to perform loading, main process, and offloading. Pneumatic cylinder is selected as actuator because it produces reciprocating linear motion with simple design and construction [24]. Simulator hazard is also required to simulate one of standardized hazardous event presented in ISO 12100 table B.2. Mechanical hazard is selected as study case because this mechanism is always occurred in every machinery, either for rotating equipment or reciprocating linear devices. Figure 4 describes selected hazardous event to be simulated.

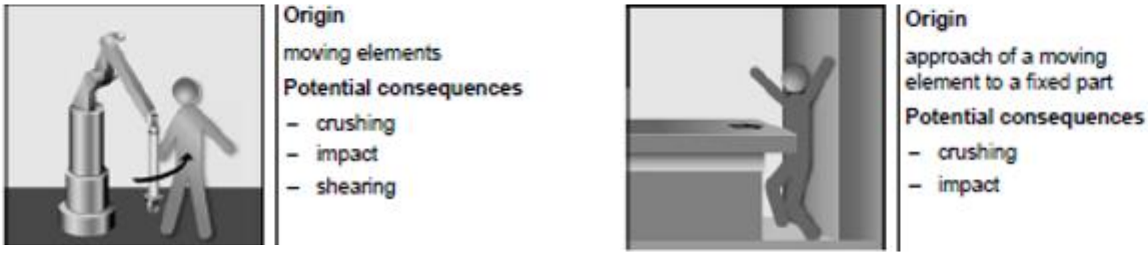


Figure 4. Mechanical Hazard [15]

2.2 Risk Matrix

Risk matrix determine the machinery safety level. It consists of four considerations, severity of harm (S), frequency of exposure (F), Probability of occurrence of the hazardous events (O), and possibility of avoiding hazardous events (A). SFOA are mapped, then generate specific risk level. Red sign indicates high risk, yellow one shows medium risk, while the green one provide low risk or safe zone, as defined in Figure 5 [10]. Initial risk level and retrofit risk level are measured and compared to prove the risk level goes down after technology retrofit.

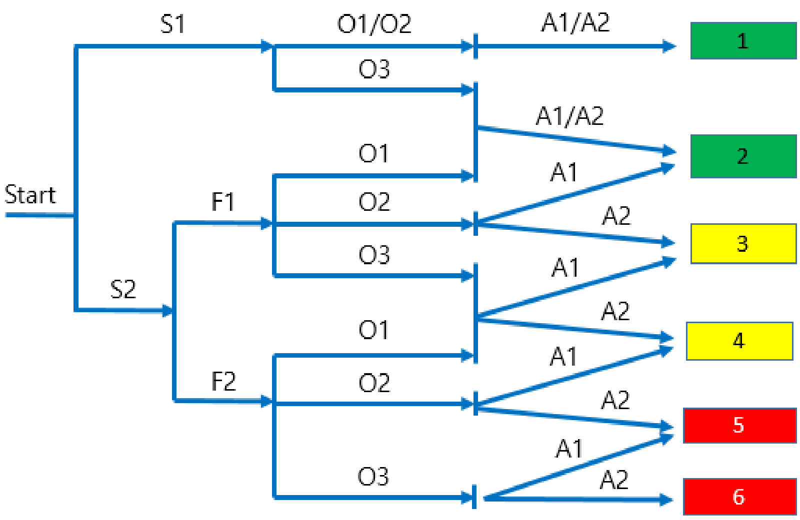


Figure 5. Defining Risk Matrix [10]

2.3 Retrofit

Retrofit in safety is defined as modification of existing technology by adding devices to reduce the risk level. Retrofit is necessary for automation machines with risk level medium or high. Previous researches performed two types of additional safety devices, separating equipment, which is usually called as safety fence [25], and non-separating, such as safety radar to identify object at specific radius [26] , and safety light curtain that utilize sensor and reflector devices to recognize the objects [27-29]. These three types of devices that are most commonly used as safety devices are compared, and the selected one need to be installed for technology retrofit.

3. Results and Discussion

Risk level of established simulator design is evaluated as initial risk level; then additional device is installed in order to reduce risk level. Comparison of retrofit risk level and initial one will be validated by direct experiment. If experiment works well, then the method is valid and can be proliferated for other types of hazard for future research.

3.1 Hazard simulator design and construction

Established simulator design comprises four design requirement and objective (DR&O); PLC as control system, pneumatic cylinder as actuator, represents mechanical hazards, and consists of three mechanisms; loading, main process, offloading. Figure 6 shows the design of simulator.

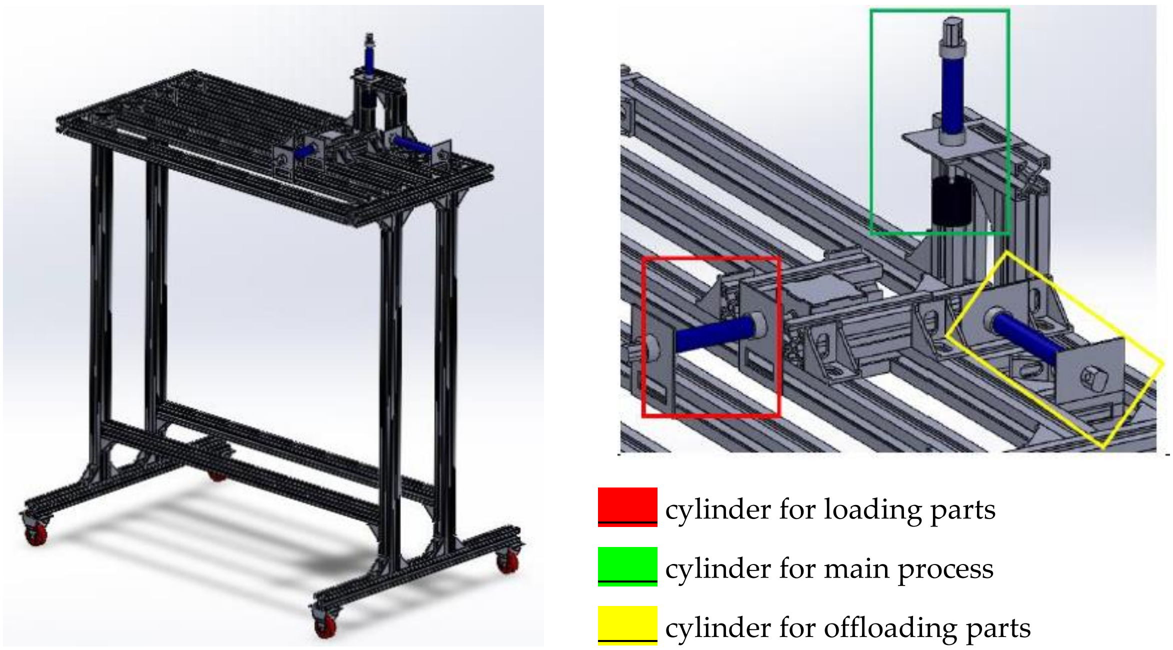


Figure 6. Mechanical Hazard Simulator

3.2 Initial risk level

The initial risk level is determined by mapping the SFOA elements presented in **Figure 5.** Each potential hazardous events described in **Figure 4** need to be evaluated. Table 1 presents the risk level of each mechanical hazard potential accidents.

Table 1. Initial risk level

Process	Mechanical hazard	Risk level
Loading	Crush & impact	Medium risk
Main process	Crush & impact	Medium risk
Offloading	Crush & impact	Medium risk

3.3 Hazard simulator retrofit

Available retrofit options to reduce risk level need to be compared from some consideration points, such as cost, simplicity, and ease of integration. Based on the considerations presented in Table 2, the most affordable option is the safety fence. **Figure 7** illustrate safety fence integration to the hazard simulator.

Table 2. Comparison of retrofit options

Retrofit options	Cost	Simplicity	Easy to be integrated
Safety fence	Cheap	Medium	Easy
Safety light curtain	Expensive	Simple	Medium
Safety radar	Very expensive	Simple	Medium

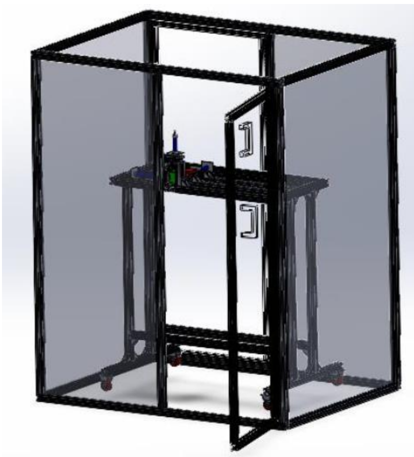


Figure 7. Safety fence cover and hazard simulator

3.4 New Risk Level

Risk level after retrofit is derived to ensure new risk level is in the safe zone (low risk). By using SFOA method, risk level comparison of mechanical hazard is presented in **Table 3.**

Table 3. Risk level comparison

Process	Mechanical hazard	Initial Risk level (Before retrofit)	New risk level (After retrofit)
Loading	Crush & impact	Medium risk	Low risk
Main process	Crush & impact	Medium risk	Low risk
Offloading	Crush & impact	Medium risk	Low risk

4. Conclusion

Established hazard simulator prove that risk level of established technology can be reduced from high/medium risk to low risk by installing safety fence cover. This simple method can be proliferated for risk assessment and risk reduction for any automation technology that hasn't been certified from safety point of view.

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